Improved object wave reconstruction in off-axis holography

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Off-axis electron holography provides access to the complete complex object exit wave [1]. This is possible by interference of the object-modulated electron wave with an empty reference wave. Subsequently, amplitude and phase are reconstructed from the recorded interference pattern. Figures of merit are both, lateral and signal resolution. Recent instrumental developments have brought significant improvements for both of them [2]. However, the reconstruction routine itself includes several pitfalls in that artifacts stemming from the imaging procedure and the detection process propagate through the reconstruction procedure and can significantly affect the reconstructed results. In addition, the limited number of electrons leads to noise in the resulting complex wave, constraining the final signal resolution in amplitude and phase.

To make sure that the finally reconstructed electron wave is representing true object information with high spatial and signal resolution, several of the limiting influences have to be analyzed and treated accordingly. Within the "Triebenberg Holography"-package designed within the DigitalMicrograph image-processing platform, the holographic reconstruction procedure has been reviewed very carefully:

In a first step, the hologram is prepared for the actual holographic reconstruction. This includes the replacement of faulty CCD pixel values such as hot spots, noise reduction of the hologram intensity by means of Wiener filtering in Fourier space, correction of the camera's MTF, and suppression of biprism Fresnel fringes.

Afterwards, the holographic reconstruction leads to a normalized complex wave. To minimize diffraction effects stemming from the reconstruction aperture ("speckle noise") a sinc-shaped reconstruction aperture is used for the sideband separation in Fourier space. This results in reconstructing a localized rectangular-shaped pixel in real space. At the same time, numerical diffraction effects caused by the reconstruction aperture are minimized. Therefore, the signal resolution, which is strongly affected by speckle noise, is improved considerably.

As examples, figs.1 and 2 show the reconstructed object exit waves of a transistor structure and an atomic resolution object wave, respectively, comparing the "old" standard reconstruction and the extended image processing procedure. Although within the examples the reconstruction provides the same spatial resolution, the "new" reconstructed object waves are much less affected by reconstruction artifacts and offer a better signal precision, hence are interpretable more accurately. [3]

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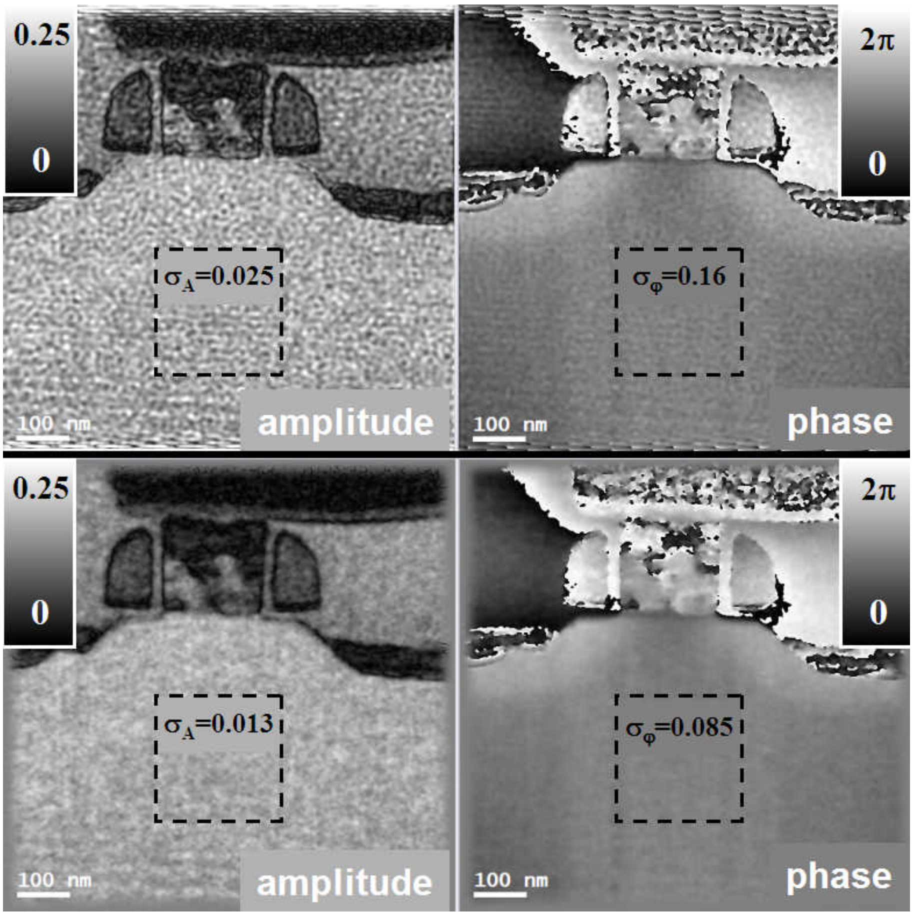

Figure 1. Medium resolution holography on a transistor structure: The "old" reconstruction (top) leads to an object exit wave that is significantly affected by artifacts, whereas the extended reconstruction (bottom) offers a much clearer access to the object information. Although the spatial resolution of 12 nm is the same for both reconstructions, the noise in amplitude and phase within the indicated areas is reduced by almost a factor of two.

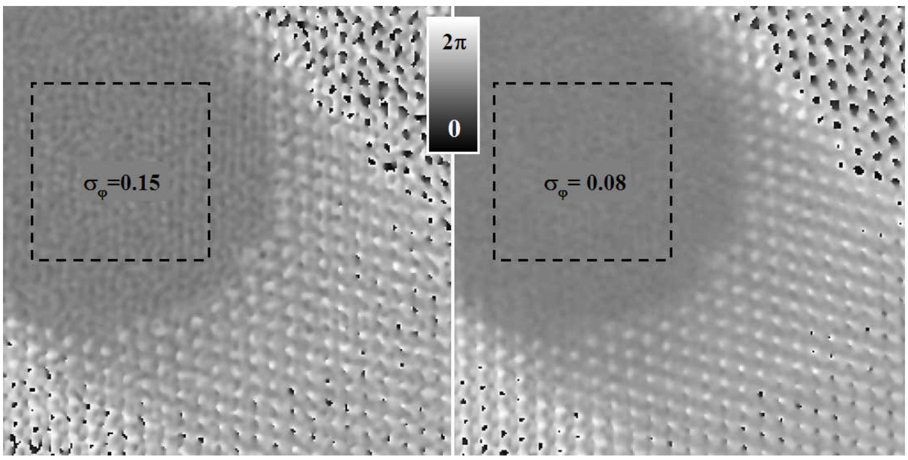

Figure 2. High-resolution holography of a gold film: The previous reconstruction (left) strongly suffers from quantum noise, because MTF-correction, which is essential for high-resolution, strongly amplifies high frequency noise. By using advanced reconstruction procedures (right), the phase noise in the indicated area is reduced by nearly a factor of two at the same lateral resolution. Note that in order to prevent averaging in real space **no** Bragg-filtering was applied. This is supported by the sharp atomic edge at the hole. The hologram was recorded by Michael Lehmann (TU Berlin).

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